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Analysis of Torques and Forces Applied on Limbs and Joints of Lower Extremities in Free Kick in Football

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Abstract

A 3- link model to simulate linear and rotational forces and moments of leg during kicking is presented. The effect of these forces and moments on lower extremity joints is studied. According to the time period of applied impact and changes in momentums of ball and foot of the picky before and after the impact, input force to system is calculated. Then, by solving dynamical equations of the system, forces and torques applied on each limb and joint of lower extremities are calculated. According to the results of this study, it is possible to scrutiny injuries of lower extremity joints.

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Keywords: free kick; soccer; sport injuries; biomechanics;

1. Introduction

Sports and particularly athletic sports like football are associated with injuries. This sport needs physical, physiological, technical and tactical skills [1]. A combination of these ingredients with increase in number of sportsmen in this field and also great tendency to contest and competition has increased prevalence of injuries in this sport field [2,3]. Chan. et. al studied on Hong Kong college student sports and considered that among collegian sports, football with 26% , has the most injuries and among the occurred injuries 67% of them are in lower extremities [4]. Drawer et. al evaluated the level of injuries in English professional football players and demonstrated that among injuries 22.2% are in ankle, 15.2% in knee, 13% in shank and 10.8% in thigh and hip joint [5].

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The most important purposes in biomechanical studies on free kick are:

- Scrutinizing the injuries caused by free kick and prevalence in football players.
- The importance of determining the forces and torques applied and demonstrate the effects of them in injuries.
- Determination of important parameters in applying impact quality of sport equipment and land.

Our purpose is to analyze forces and torques applied on joints and limbs of lower extremities in free kick in football and to understand the relationship between these forces and moment and injuries in lower extremities in free kick and therefore to help in preventing injuries while having good performance in efficient kicks .

2. Methods

This research is a case study. In this research we used lower extremity one-side 2-Dimentional kinematical analysis. Video recording was in sagittal plane by use of infrared camera with frequency of 250 Hz in National Academy of Olympic and Para Olympic situated in Enghelabe-Tehran sport caboodle. The camera was situated 3 meters far away from the sport man. 4 optic markers were set on one-side in front of the camera. The markers delineate toe, ankle, knee and hip joints. Stroking was started from stand up position as is shown in fig 1.a. Time period of kicking is 4×1/250=0.016 sec and impact was direct that means Faheraeus-Lindquist effect is neglected. As is shown in fig 1, ball is in 62.83 cm of foot of the picky. After video recording, pictures were captured with frequency of 250 Hz. Center of geometry of each marker in each frame was precisely illustrated with the aid of picture processor software which was designed for this purpose. By having these data in each moment (frame) other kinematical and geometrical data by using Matlab or Excel soft wares were calculated for all other frames. Fig 1.b shows the first contact of foot with ball (frame number 147 in 0.588s after stoking). Fig 1.c shows geometry position of each limb in one of middle frames (frame number 159 in 0.636 s after stroking). Fig 2 shows the flow chart of proceeding through which we get kinematical data. Data obtained include position, velocity, acceleration of each marker (joint) and also length, angle with respect to horizon line, velocity and acceleration of each link (limb). By using these data and anthropometry table for the picky, forces and moments of each limb and joint are obtained after performing below steps. Equations were solved for all frames in Excel.

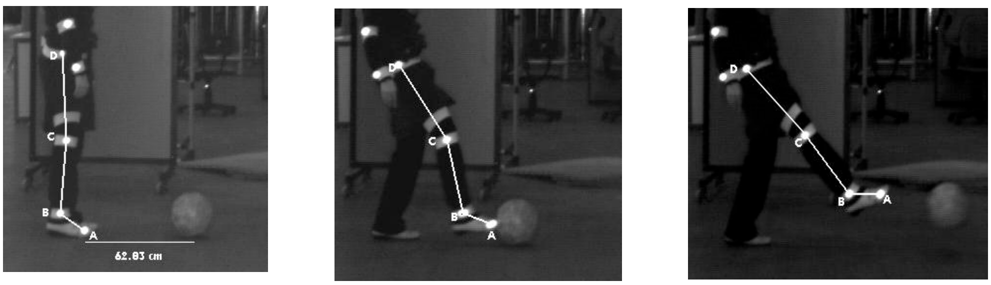


Fig. 1. (a) Initial position for kicking (left); (b) first contact of foot with ball (middle); (c) geometry position of each limb in one of middle frames (right)

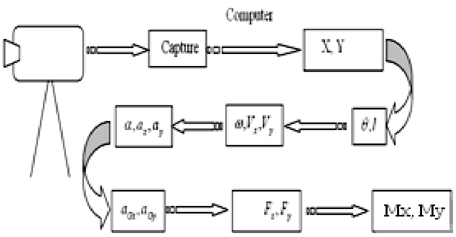


Fig. 2. Data processing

Step 1*: determination of centre of gravity of each limb (x_{Gi}, y_{Gi}).*

The geometry is shown fig 3.a.

$$x_{Gi} = x_j + \vec{r}_i \cos\theta_i \quad (1)$$

$$y_{Gi} = y_j + \vec{r}_i \sin\theta_i \quad (2)$$

Step 2*: determination of centre of gravity accelerations for each limb (a_{xGi}, a_{yGi}).*

The geometry is shown in fig 3.b.

Step 3*: determination of changes in ball momentum (G_{xin}, G_{yout}).*

Ball is in stationary position before kicking like in free kick so:

$$\Delta\vec{G} = m\Delta\vec{v} = m(\vec{v}_{out} - \vec{v}_{in}) \quad (3)$$

$$\vec{v}_{in} = \vec{0} \quad (4)$$

Step 4*: determination of external forces (F_{xave}, F_{yave}).*

By neglecting the changes in impact force and solving below equations, average of impact force is calculated. In equation (6), n is the number of frames in which foot and ball are in contact with each other (4 frames: frame number 147-151).

$$\int \vec{F}dt = \Delta\vec{G} \rightarrow \vec{F}_{ave}.\Delta t_{impact} = \Delta\vec{G} \quad (5)$$

$$\Delta t_{impact} = \frac{1}{f} \times n_{impact} = \frac{4}{250} = 0.016(\text{sec}) \quad (6)$$

Step 5*: determination of forces generated in each joint (F_{xj} F_{yj}).*

Step 6*: calculating gyration radius and inertia moment for each limb (r_{Gi} , I_{Gi}).*

$$r_{Gi} = \left[l_i \times \frac{r_{Gi}}{segment - length} \right] \quad (7)$$

$$I_{Gi} = \bar{I}_i = m_i \times r_{Gi}^2 \quad (8)$$

Step 7*: determination of moments applied on each joint (M_{zj}).*

The geometry is shown in fig 3. c.

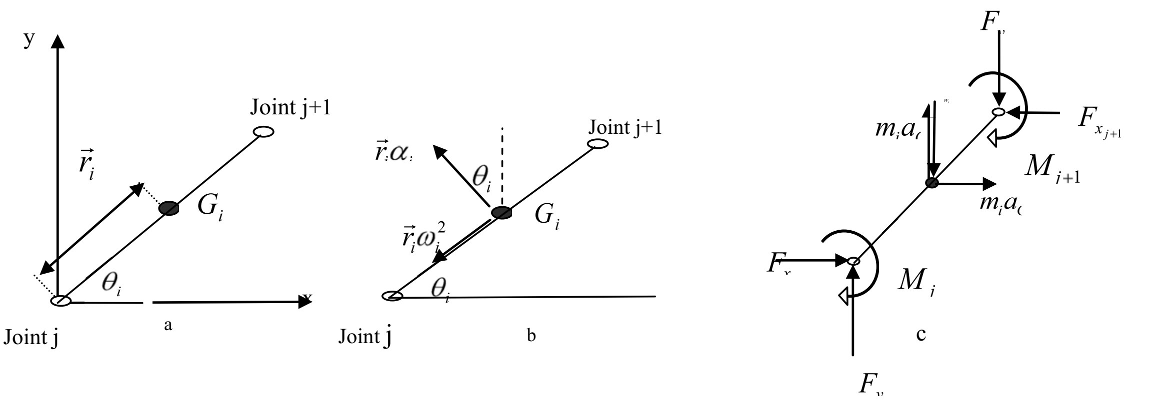


Fig. 3. (a) Determination of COG of each limb (left), (b) determination of centre of gravity accelerations for each limb (middle), and (c) determination of moments applied on each joint (right)

3. Results

The kicking was captured in 269 frames. The light intensity as was shown in fig 1 was set so that the markers could be distinct and vivid. Anthropometric characteristics for the picky are shown in table (1). Table (2) shows the results of calculating changes in momentum of ball (G_{xin}, G_{yout}) and also external forces (F_{xave}, F_{yave}). The graphs of forces and moments on each limb and joint during kicking are shown in fig 4 and fig 5 respectively velocity of each limb and acceleration of each joint during kicking is shown in fig 6.and fig 7 respectively.

Table 1. Anthropometric parameters

value	Picky anthropometric parameter quantity*	Ratio	Anthropometric parameter
0.7685 kg	Foot weight	0.0145	Ratio of Foot weight to body weight
2.418 kg	Shank weight	0.0465	Ratio of shank weight to body weight
5.2 kg	Thigh weight	0.1	Ratio of thigh weight to body weight
12.16 cm	Foot Center of mass from distal point	0.5	Center of mass from distal to foot length
22.31 cm	shank Center of mass from distal point	0.567	Center of mass from distal to shank length
22.22 cm	thigh Center of mass from distal point	0.567	Center of mass from distal to thigh length
11.552 cm	Radius of Gyration from center of gravity	0.475	Radius of Gyration from center of gravity to foot length
11.89 cm	Radius of Gyration from center of gravity	0.302	Radius of Gyration from center of gravity to shank length
12.66 cm	Radius of Gyration from center of gravity	0.323	Radius of Gyration from center of gravity to thigh length

*picky weight and height are 52 kg and 160 cm respectively.

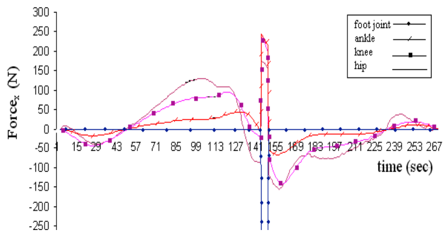
Table 2. Moment of inertia for each segment

Value	Moment of inertia for each segment (limb)
0.010	Foot
0.034	Shank
0.083	Thigh

Table 3. external forces and ball momentum.

Gin*	Gxout	Gyout	Fxave	Fyave
0	4.1968	0.92344	262.3	57.715

*ball was in static position before kicking means: $v_{in} = 0 \Rightarrow G_{in} = 0$



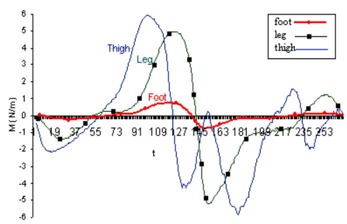


Fig. 4. Forces applied on each joint versus time during kicking (a) in x direction (left); (b) in y direction (right).

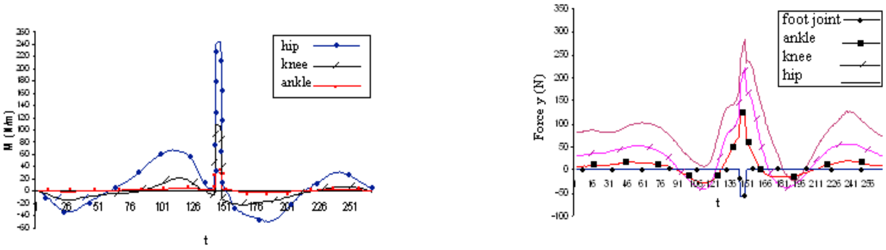


Fig. 5. Moment versus time during kicking. (a) moments of each joint (left); (b) moments of each limb (right).

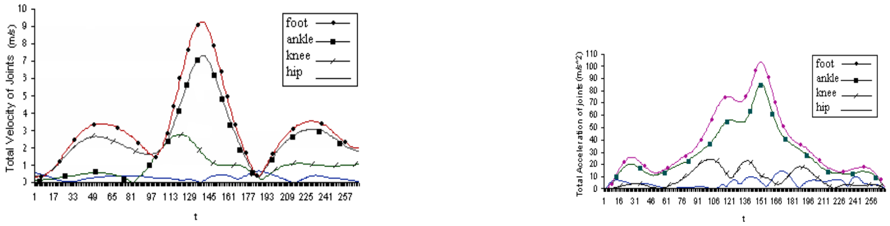


Fig. 6. (a) Velocity for each joint versus time during kicking; (b) acceleration for each joint versus time during kicking.

4. Discussion

As was considered in graphs, maximum velocity and acceleration of toe and ankle are at the instant of contact of foot with ball. Maximum rotational velocity of shank is at this time, too. Thigh and ankle reach the maximum rotational velocity before shank as, toe reaches its maximum rotational velocity just before stroking. Maximum acceleration of toe COG in x direction is at the moment of contact between toe and ball. At this moment a great impact force is inserted to foot and with Newton's law $\sum F = ma$ with increasing in force and mass remaining constant, therefore acceleration increases. Maximum foot COG acceleration in vertical direction is also nearly at this moment. Shank and thigh reaches the maximum acceleration after this moment but with lower extent respectively. positive amount of applied force on lower extremity joints increases from toe to hip because, during kicking, the kicker leg is suspended in the air. Though lower member weight is beard by upper limbs vice versa to the condition in which foot is on the ground. At the time of applying impact (frame numbers 147-151) a great impact force is inserted to the foot of the picky which in x direction by using dynamic relations and Newton's second law, is transmitted to upper joints and in y direction is added with lower limbs weight and then transmitted to upper joints. The joints' moments also increase from toe to hip that's because of increase in force and moment arm. Presumably, mechanical characteristics of ball like jump coefficient, inside pressure, elastic and damping coefficient have considerable effects on time period of applied force and therefore in changes in ball momentum and force inserted to foot. The distance between kicker and ball as was shown in fig (1) and also spin of ball (Faheraeus- Lindquist effect) have effect in results. The results of this project are in good accordance with other similar works. It should be considered that dynamical analysis used in this project for calculating muscle forces (which result in joint or limb forces) in free kick, is a new approach and hasn't used in other papers. But, kinematic parameters and other kinetic parameters are in good accordance with results presented by other researchers(1). The results presented in this paper can be used to determine the effects of free kick on muscles, tendons, ligaments, joints' surfaces in hip, knee and ankle joints. Hence, it's not only possible to forecast the possibility of injuries but also correction of sport movements with the aid and guidance of teacher. Muscles co contraction for increased stability results in simultaneous force generation in both agonist and antagonist muscles. This is the most restriction in accuracy of results obtained. It's suggested for controlling this interrupting factor, EMG of the regions in which this phenomenon occurs at the time of co-contraction of muscles should be recorded. So, by recognizing the periods of mentioned restricting phenomena, schematization for elimination and control of it can be performed. By determining maximum force that quadriceps muscle can bear for each athlete maximum range of ball in free kick can be determined and vice versa. By calculating maximum force of quadriceps with EMG and then multiply it by moment arm from knee joint, maximum torque generated in knee joint is determined. By having maximum moment that knee can bear without serious injury, and by solving dynamic equations maximum torque at foot is calculated and so on maximum force which results in maximum range of ball in kicking associated with this maximum moment of knee and also vice versa. Therefore maximum range of ball without serious harm and injury to knee joint which is very susceptible for injuries can be calculated for each athlete.

The results and information of this paper can be used in schematizing for preventing injuries and help considerably teachers and especially medic cadres of sport teams.

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